RESEARCH ARTICLE

Preliminary Experimental Performance Study of Hybrid Solar Thermal Collector Coated with Spectrally Selective Polyethylene Terephthalate Film

NwajiG.Nnabuihe[1*],Ononogbo Chibuike[2],Ezeome C.Uzochukw[1], Mba V.Ndukwe[1], Anukam D. Chidiebere[1], Nwereonye T.Chigozie[1], Ebirim Prince[1], Oborakpororo O.Righteous[1], Chima Ike[1], NnamdiV. Ogueke[1,3], Anyanwu E.Emmanuel[1]

[1]Federal University of Technology, P.M.B. 1526, Owerri, Imo State, Nigeria
[2]University of Agriculture and Environmental Sciences, Owerri, Imo State, Nigeria
[3]African Center of Excellence on Future Energies and Electrochemical Systems (ACE-FUELS), Federal University of Technology, P.M.B. 1526, Owerri, Imo State, Nigeria

ABSTRACT: The performance evaluation of a dual flat-plate solar thermal collector suitable for diurnal heating and nocturnal cooling applications is presented. Two collectors, each with estimated area of 0.784 m^2 were designed, developed and experimentally investigated. The plates were made with mild steel and coated with matte black and polyethylene terephthalate (PET) powder. The results obtained showed that in the diurnal heating mode, the hybrid plate attained a maximum temperature of 68.8°C while the ambient temperature ranged from 25.3°C-30.4°C, at a peak insulation of 937.3W/m^2during the test period. In the nocturnal cooling phase, the hybrid plate attained a minimum temperature of 21.3°C, while the ambient temperature ranged from 23.4°C-24.3°C. During the nocturnal phase at clear sky, the maximum water temperature drop recorded was about 10.3°C. Also,8°C difference in temperature occurred between the top water zone and the bottom zone in the tank, signifying a clear thermal stratification in the tank. The overall performance of the system revealed that the device is a promising technology in locations that have similar climatic conditions as Owerri; thus, showing a dual-purpose seasonal adaptability and energy saving capabilities. Therefore, an installation of the device into a building can ensure a supply of domestic hot water for domestic and other activities all year round. The system can also deliver heat for comfort heating in cold seasons or for comfort cooling during periods of elevated ambient temperatures, hence offsetting the seasonal energy bills in a building.

KEYWORDS: Experimental, Heating, Cooling, Thermal Performance, Spectrally Selective, PET

https://doi.org/10.29294/IJASE.8.4.2022.2360-2370

1.INTRODUCTION

Due to high cost of fossil fuels as well as the numerous environmental challenges associated with their usage, the world's attention is gradually shifting to cleaner and renewable energy sources. Energy and power optimization have been a recurring topic globally, with major interests on space and fluid heating. Thus, for many decades, there have been successful activities on the exploration of renewable and cleaner energy resources for both domestic and industrial heating and cooling applications. According to [1], greenhouse gas emissions have become predominantly high and characteristic of conventional power units. The traditional means of power generation for domestic and industrial applications involves the combustion of fuels of fossil origin such as coal, wood, petroleum, etc. And this collectively accounts for 80% of the total energy consumed globally, while renewable energy resources comprising solar, hydro, biomass and geothermal accounts for 13.5%, and nuclear power accounts for only 6.5% of the total energy consumption [2]. Renewable energy sources have clean production and operation processes and are harmless to the environment. Technology advancements is driving increased investment portfolio in renewable energy harnessing in an economical manner like never before reported that by the year 2017 [3], countries generating more than 100MW from renewable would have seriously increased.

**Corresponding Author: godswillmee@gmail.com*
Received: 10.03.2022 **Accepted:** 27.04.2022 **Published on**: 18.05.2022

Nigeria as well as many other African countries have sufficient renewable energy resources such as hydropower, wind, biomass and solar, with her large and small hydropower resources which are barely tapped estimated at 10,000 MW and 734 MW, respectively; whereas annual solar radiation and biomass are estimated to be 3.5–7.0 kWh/m^2 and 144 million tons, respectively [1].According to [4], solar thermal systems find application in solar water heating, even though the application is affected by the problems associated with effective solar energy collection and storage. As an environmentally friendly substitute for fossil fuels, the technology can be successfully applied both domestically and industrially, resulting in savings in energy cost [5,6]. The solar thermal collector is the major part of solar water heating systems as it captures and converts insolation into useful energy that produces hot water [5].

Research findings have shown the potential of solar radiation for space cooling and heating. Solar thermal devices collect the sun's energy and convert it into heat that may be useful in raising the temperature of a fluid (air, water, etc.) for heat transfer applications [7] reported that a flat-plate system normally operates and attains its maximum efficiency within the temperature range of30 to 80°C [8] reported that the different types of materials used are usually tweaked and selected to achieve different output temperature ranges. According to [9], flat plate collectors are suited for situations of appreciably high solar radiation intensity. However, their benefits are reduced on their exposure to cloudy, windy, and cold weather conditions. In addition, the tubes and the available insulation exhibit the tendencies to deteriorate, thereby causing losses on performance. The rate of heat losses is one of the main factors affecting the thermal performance of solar thermal collectors. Thus, the overall efficiency of a solar thermal collector is improved by minimizing heat losses. The reduction in collector heat losses is achieved by ensuring that more of the incident solar radiation is collected and used effectively, hence assisting in the offset of conventional energy bills. Furthermore, the geographic orientation and tilt angle of the collector can affect the performance of the system as it determines the amount of daily solar energy it receives. Owerri is in the Northern hemisphere, hence to effectively capture solar energy, the optimum orientation of the collector must be due south, and the collector should be tilted so that it is more nearly perpendicular to the solar rays. According to literature reports, the optimum angle of tilt for a location should correspond to its latitude angle (θ) or the angle of latitude +15°so as not to reduce the solar output [10, 11, 12, 13].

Nocturnal radiative cooling (NRC) is an effective natural passive cooling technology that utilizes the exchange of infrared radiation between the sky and the surface of the earth [14]. The earth is warmed up during the day by receiving heat from the sun's radiation, but during the night hours, the heat is radiated to the sky, as the sky acts like a heat sink. This is because the sky at night is usually colder than the earthly surfaces, thus any surface that is exposed to the sky at night loses heat and experiences a fall in its temperature; and this is the concept of NRC [15, 16,12,17]. Since NRC is a natural passive cooling process, its performance depends ultimately on weather conditions; and according to [18] and [19] variations in seasonal factors such as cloudiness, humidity and winds impact significantly on the intensity of nocturnal cooling.

The hybrid solar thermal collector proposes a cleaner and more efficient way of generating heat for space heating, domestic hot water (DHW) and cold-water preparation, thus evading intensive energy costs and reducing the total consumption of fossil fuels.According to [20] hybrid systems are systems that have the capacity to perform diverse functions as a single unit, namely solar electricity generation, space cooling and solar water heating. The development of hybrid systems was mainly due to the problem of inefficiencies and high cost associated withstand-alone systems that limit their broad implementation [21,22,6,17]. There are numerous works in recent times that are targeted at exploiting the ambient environment for the achievement of space conditioning. Thus, the solar collector-nocturnal radiative cooler has proven to be effective in providing appreciable levels of heating and cooling of water, and space comfort cooling and heating when integrated with building envelopes [12, 17]. This work considered the development and performance evaluation of a hybrid solar thermal collector-nocturnal radiator using a locally sourced PET powder made from waste PET bottles to ascertain the thermal performance of the system in the entire solar and atmospheric window spectra under Owerri Climatic conditions.

2. Heating and cooling performance Calculations

2.1 Collector useful energy

The solar thermal collector's useful energy was calculated by [23];

$Q_u = A_c[S - U_L(T_p - T_a)]$ --- (1)

where A_c is the collector area, S is the absorbed solar energy, U_L is the coefficient of overall energy loss,T_p is the plate temperature, T_a is the ambient temperature.The absorbed solar energy is given as:

S = $(\tau\alpha)_{av} I_T$ ---- (2)

where$(\tau\alpha)_{av}$ is the average of the product of transmittance and absorbance of the plate material and I_T is the total incident solar irradiation.The overall energy loss term is expressed as:

$U_L = U_t + U_b + U_e$ ---- (3)

where U_t is the top loss co-efficient,U_b is the bottom loss co-efficient and U_e is the edge loss coefficient, all in W/m^2K.

2.1.1 Thermal losses

Top Losses

Under conditions of steady state, the transfer of heat to the PET cover (glazing material) from the absorber plate is the same as the energy lost to the ambient from the PET cover[24]. Therefore, the heat lost to the PET cover from the absorber plate is given as:

$$Q_{ab-PET} = A_c h_{c,p-PET}\left(T_p - T_{PET}\right) + \frac{A_c\sigma({T_p}^4 - {T_{PET}}^4)}{(\frac{1}{\varepsilon_p}) + (\frac{1}{\varepsilon_{PET}}) - 1} \text{ ---- (4)}$$

where A_c is the collector area (m^2), $h_{c,p-PET}$ is convective heat transfer co-efficient (Wm^2/^{0}C) between the absorber plate and the PET cover, $T_p and T_{PET}$ are the plate and PET cover temperatures (^{0}C) respectively, $\varepsilon_p and \varepsilon_{PET}$ are infrared emissivity of absorber plate and PET cover, respectively; and σ is Stefan-Boltzmann constant ($5.67 \times 10^{-8} W/m^2k^4$).

For a collector inclined at β (^{0}), the convective heat transfer co-efficient, $h_{c,p-PET}$ was obtained using from [23]:

$$N_u = \frac{h_{c,p-PET}L}{k} = \left(1 + 1.446\left[1 - \frac{1708}{R_a \cos\beta}\right]^+ \left[1 - \frac{1708\sin(1.8\beta)^{1.6}}{R_a \cos\beta}\right] + \left[\frac{R_a \cos\beta}{5830}\right]^{0.333} - 1\right) \text{— (5)}$$

where R_a is the Rayleigh number, L is the cover distancefrom absorber to PET in (m). Note the plus sign (+) at the top of the bracket stand for positive values only. The value ofR_a is given by,

$$R_a = \frac{g\beta' P_r}{v^2}(T_p - T_{PET})L^3 \text{ ----(6)}$$

temperature given as:

$$T_m = \frac{(T_p + T_{PET})}{2} \text{ ----(7)}$$

Bottom Losses

The loss of energy through the collector back is due to the conduction through the insulation at the back, as well as the convective and radiative heat transfer to the surroundings from the back of the collector. Since the thermal resistance magnitudes for both convective and radiative heat transfer are relatively small in comparison to that of conduction, an assumption that all the thermal resistance from the back was as a result of conduction through the back insulation. The back-heat loss, Q_b was obtained using Eq. 8.

$$Q_b = \frac{K_b}{L_b} A_c\,(T_p - T_a) \text{ ---- (8)}$$

where L_e and k_e are thickness and edge insulation thermal conductivity, respectively.

Edge Losses

For most available collectors, it is usually difficult to evaluate edge losses. However, in an efficiently fabricated system, edge losses are expected to be very small, for which reason their accurate estimation is not necessary. Besides, considering the heat flow within the collector's perimeter to be one-dimensional, the edge losses were evaluated from Eq. 9:

$$Q_e = \frac{k_e}{L_e} A_e (T_p - T_a) \quad \text{--- (9)}$$

where L_e and k_e are thickness and edge insulation thermal conductivity, respectively. Therefore, the total heat loss from the collector was estimated by the substitution of Eqs 7, 8 and 9 into 4, resulting in:

$$Q_L = Q_{ab-PET} + Q_b + Q_e \text{ ----(10)}$$

2.2 Nocturnal Cooling

Nighttime cooling is governed by the basic physics of radiation to the night sky. This phenomenon takes place because of heat loss through long-wave radiation from one body to another (at a lower temperature) that acts like a heat sink. The materials used for the achievement of nighttime radiative cooling must have high emissivity that is capable of delivering a significant effect of radiation in the atmospheric window (8-13μm. The radiation from the system was calculated using the expression:

$$P_{rad} = \mathrm{A}\varepsilon\sigma \mathrm{T}_{sys}{}^{4} \text{ ---- (11)}$$

where P_{rad} is the radiation from the system, A is the area of the collector, ε is the PET powder emissivity, σ is the Stefan Boltzmann constant and T_{sys} is the temperature of the system.

The total cooling power was calculated from [25]:

$$P_{cool} = P_{rad} - P_{sky} - P_{sun} - P_{cond\,+\,conv} \text{ ---(12)}$$

where P_{sky} is heat gain from the sky. P_{sun} which is the heat gain from the sun was assumed zero since the study was conducted at night, $P_{cond\,+\,conv}$ was neglected since the plate and tubes were in perfect contact.
The heat gain from the sky was calculated from:

$$P_{sky} = \mathrm{A}\varepsilon_{\mathrm{sky}}\sigma \mathrm{T}_{amb}{}^{4} \quad \text{---(13)}$$

2.23 Collector Thermal Efficiency

The efficiency of the thermal collector can be estimated using the correlation:

$$\eta = \frac{Q_u}{Q_u + Q_L} \times 100\% \quad \text{---(14)}$$

Where $Q_u$is the useful energy and $Q_L$is the energy lost to the ambient.

3. Experimental Setup and investigation procedure

The test was conducted on a locally fabricated 1.57m^2 solar thermal collector, divided into two thermal collectors, each with estimated area of 0.784m^2, as shown in Fig. 1. The system was installed at the Procurement Building, Federal University of Technology Owerri, South East Nigeria ((5.49^{o}N, 8.67^{o}E) and mounted facing South at a tilt of latitude plus 15^o. The plates were made with mild steel and coated with matte black and polyethylene terephthalate (PET) powder. The Matte black was to enhance the plate absorptivity while the PET coating was to enhance night-sky cooling. The setup is composed of two flat plate collectors, each with an estimated area of 0.784m^2, linked together, a vertically placed storage tank, as well as upper and down hoses connecting the tank to the plates. Each plate had 12 copper tubes welded underneath with inside and outside diameters of 12.7mm and 13.1mm, respectively, and spaced 40.25mm apart. Other specifications of the system are given in Table 1.

The instrumentation comprised only several temperature measurements, solar irradiation and wind data. Five temperature measurements were taken on the surface of the absorber plate (designated as PT1, PT2, PT3, PT4, PT5). PT3 is at the midpoint between two tubes, PT1 is atop the plate where the tube is attached while PT2 is located between PT1 and PT3. PT5 and PT4 are mirror image points of PT1 and PT2, respectively on the other side of the tube. Another temperature point was taken on the copper tube underneath, designated as CT. Three temperature measurements were taken on the storage tank (T1, T2 and T3), and one each at the inlet (T_i) and outlet (T_o) to and from the tank, respectively, as shown in Fig. 2. The temperatures were measured by DS18B20 sensors. The ambient temperature and relative humidity data were also recorded using the same sensors. Furthermore, solar irradiance and wind velocity data were manually recorded every 30 minutes with a Solarimeter and Anemometer, respectively. A 16-channel data logger was used to collect the temperature data from the plates, tank and the ambient as well as the relative humidity. Data were collected at 30 minutes intervals for an entire day spanning 8:00 am, 5th of August to 8:00 am, 6th of August, 2021.

The collected data were grouped into the day and night cycles. The night cycle started by 6pm, the water was changed and the process was repeated. The day readings considered the heating power of the thermal collector, whereas the night readings gave a consideration of the cooling power of the system.

Fig. 1: Experimental Set-up

Table 1: System specifications			
Collectors		**Storage tank**	
Type	Flat-plate	Orientation	Vertical
Tilt angle	20.5°	Material	Plastic
Area	0.784m^2 x 2	Thickness	5mm
Thickness	0.05m	Insulation	Aluminum foil, 5.1mm
Absorptivity	0.92	Volume	120 litres
Glazing/windscreen	HDPET		
No of risers	12	**Connecting hoses/tubes**	
Riser inner diameter	12.7mm	Inner diameter	14mm
Insulation	Fibre glass	Insulation	Aluminum foil, 5.1mm
Efficiency	45.7%		
Frame	Plywood		

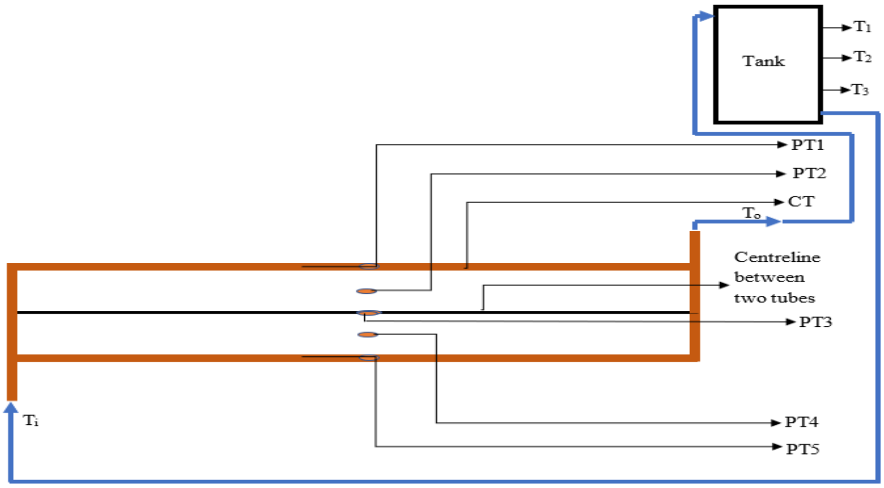

Fig. 2: Positioning of measurement sensors on the plate and tank

4. RESULTS AND DISCUSSION

As shown in Fig. 3, at early hours of the day little temperature variation between the ambient and plate can be observed, due largely to the fact that the irradiation intensity at this time is small. As the test continued the plate temperatureexperienced a gradual increase and reached its peak of 68.8°C at 2:00pm, whereas about the same time, the solar irradiation attained its peak of 937.3W/m^2. Thereafter, the plate temperatures decreased slightly as the solar irradiance experienced a sharp drop; and the temperatures continued to decrease significantly as solar irradiation continued to decrease. However, at 4:00pm, the plate temperatures increased again albeit slightly when the solar irradiance experienced another increase. At sunset, the solar irradiation kept decreasing, reaching its minimum recorded value of 148.9W/m^2 at 6:00pm, thus causing the plate temperatures to reduce as well, following the solar irradiation trend. This shows that as the solar irradiation increases, the plate temperatures also increase, and as the solar irradiation decreases, the plate temperature also decreases.This is consistent with the report of some researchers that peak plate temperature occurs at 2:00 pm or after a delay period of about one hour [26, 12] though with varying magnitudes of the maximum temperature, which can be as a result of contact resistance influence provided by the bond connecting the plate to the tube.

The temperature profile in storage tank is as shown in Fig. 4. It can be observed that the average storage temperature in the tank attained about 40°C at 4:30pm. This is an acceptable limit based on the size of the plate used for the test. The bigger the collector size, the larger the energy is deliverable to the tank. It was also observed that the average temperature at the inlet of the tank (T_i) was greater than the average temperatures T_1, T_2, T_3, respectively, showing that the water was heated as it moved through the collector. From the temperature profile, it is evident that thermal stratification occurs in the tank as the difference in temperature between the top water zone and the bottom zone at 2:00 pm is about 8°C. Also, to corroborate the fact thermal stratification is occurring, the temperature of the bottom zone (T_3) remained almost unchanging till about 12:00pm whereas the top zone temperature (T_1) was increasing during that same period. The energy input at this time is not enough for inter-zone heat transfer within the storage tank.

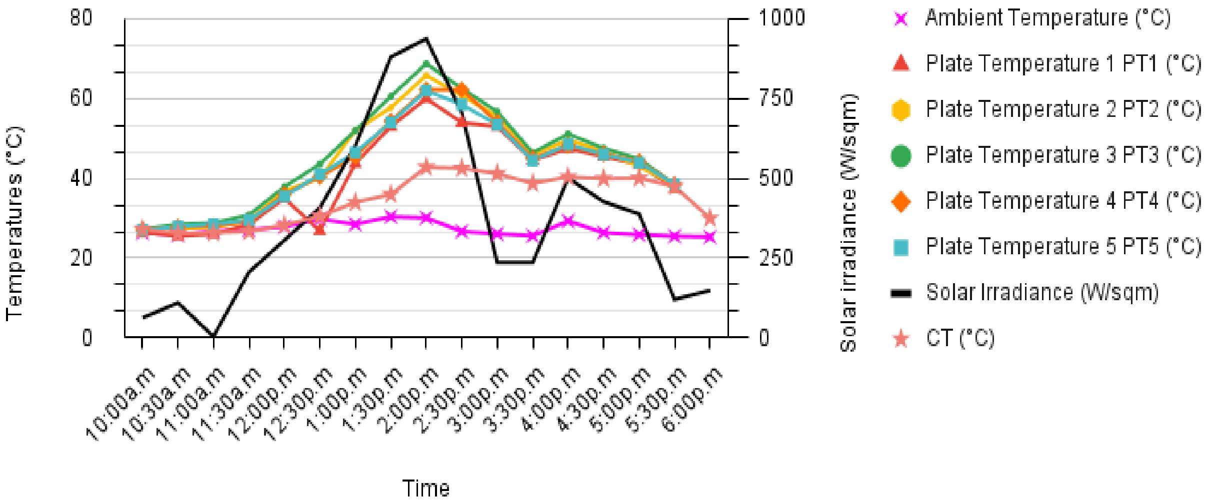

Fig. 3: Time variant temperature data for the plate, tube and ambient during diurnal heating

From Fig. 5, it is evident that at the beginning of the test, the ambient, collector tube and inlet water temperatures of the first collector were relatively close ranging from 25.13-27.19°C at 10:00am. As the solar irradiance increased, the collector tube temperature also increased and a peakof 42.81°C was achieved at 2:00pm, thusleading to a rise in the inlet and water temperatures of the first collector. The exit temperature of the water in the first collector was also greater than its inlet temperature,because as the water traveled

through the tubes, it continued to pick up heat along its length, thus leading to a higher temperature at the exit of the tube. Furthermore, as the tube temperature decreased, the water temperature at both the inlet and exit of the first collector did not decrease but kept increasing slowly as seen from periods beyond 2:00pm. This decrease in the tube temperature and corresponding increase in the water temperature in the inlet and exit parts of the first collector continued until they assumed almost same valuesfrom 5:30pm.Since the hose connecting the collector to the tank and that connecting the tank to the collector are perfectly insulated thus minimizing losses, it is expected that the collector outlet temperature is equal to the tank inlet temperature and the tank outlet temperature is equal to the collector inlet temperature. The low temperature recorded in the tank might be due to imposed flow rate and collector size used as well as the irradiation level arising from the season during which the experiment was conducted.

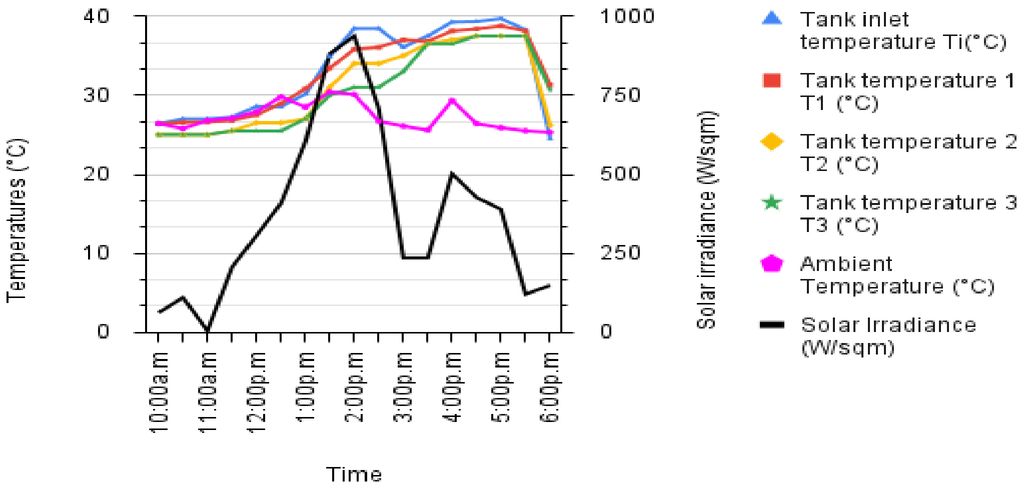

Fig. 4: Time variant tank and ambient temperatures during diurnal heating

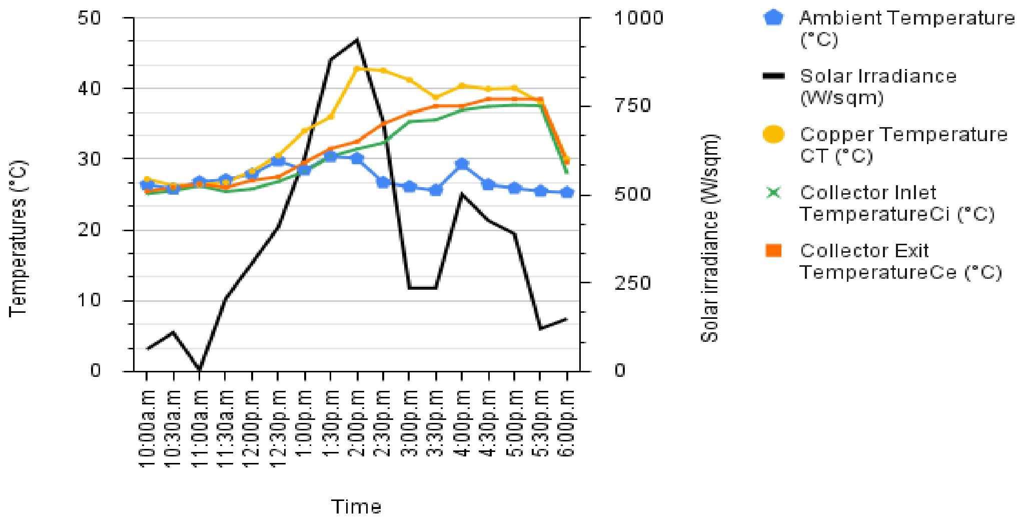

Fig. 5:Time variant ambient, collector inlet and outlet water, and copper tube temperatures during diurnal heating

From Fig. 6, it can be observed that at the beginning of the test, the energy loss at the bottom and the energy loss at the edge progressed gradually. When the solar irradiance increased, the collector tube temperature increased and peaked at 42.81°C around 2:00pm, leading to an increase in the quantity of energy losses of 48.54W and 7.95W at the bottom and at the edge, respectively.

The nocturnal collector mode test was performed at a clear night from 6:30pm on August 5, 2021 to 6:00am on August 6, 2021. Readings were also collected at intervals of 30 minutes and presented in Figs 7-9.From Fig. 7, it was observed that the temperature of the plate reduced gradually with time signifying radiative cooling at nighttime. At about 3:30am, the temperature of the plate went below the ambient temperature reaching a minimum value of 21.36°C at 6:00am, meaning it has cooled 2.24°C below ambient at this time.

Fig. 6: Graph of edge (Q_e) and bottom Q_b losses with time during diurnal heating

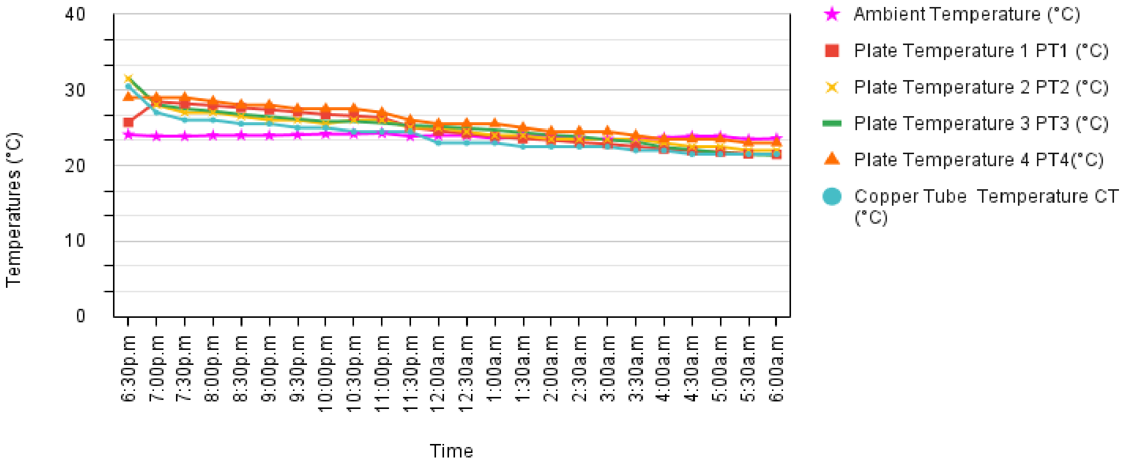

Fig. 7: Time-variant ambient, plate and tube temperatures during nocturnal cooling

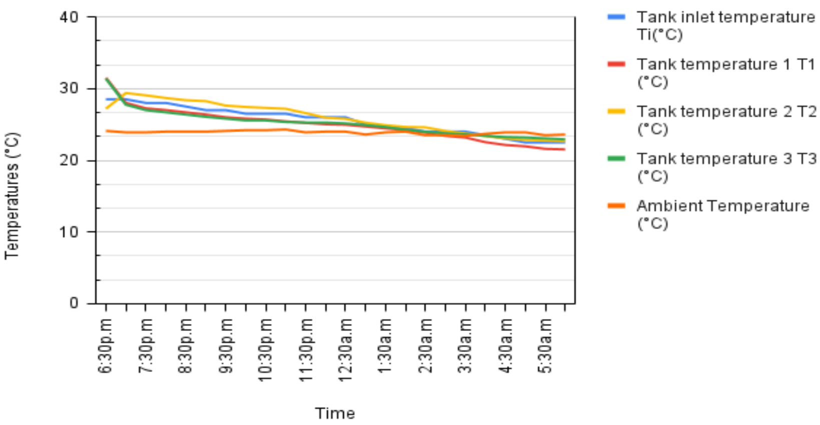

Fig. 8: Time-variant ambient and tank temperatures during nocturnal cooling

NwajiG.Nnabuihe., et al.,

The variation of the tank temperature with time during the night hours is as shown in Fig. 8. The temperature of water at T_1, T_2, T_3 and T_i decreased with respect to time and reached their minimum at 6:00am. The temperature of water at the designated zones or points in the tank also decreased below the ambient temperature at 3:00am. The essence of the hybrid system is to store hot water for use mostly in the morning hours when there is no irradiation and also to store cold water for use during the next day after the night cooling operation which probably would be harnessed for hydrant space cooling. Achieving these two purposes would entail using two separate storage tanks. However, one storage tank has been used in this demonstration. As at 1:00 am, water at 28°C could still be drawn from the tank.

From Fig. 9, the water temperature at inlet and outlet of the first collector, and the temperature of the collector tubes reduced with time. This reduction in temperature signifies the loss of heat from these points to the plate and thus the cooling effect.The current investigation has achieved 2.24°C depression below ambient during night-sky cooling in Owerri. In the same climate under investigation, [27] reported a cooling below ambient of about 2.5 °C, [28] in a similar study reported 1–1.5 °C cooling below ambient while [12] reported 2.51°Cbelow ambient, respectively, during nocturnal cooling. However, [29] reported 7-8°C deviation during a clear sky in Iran.

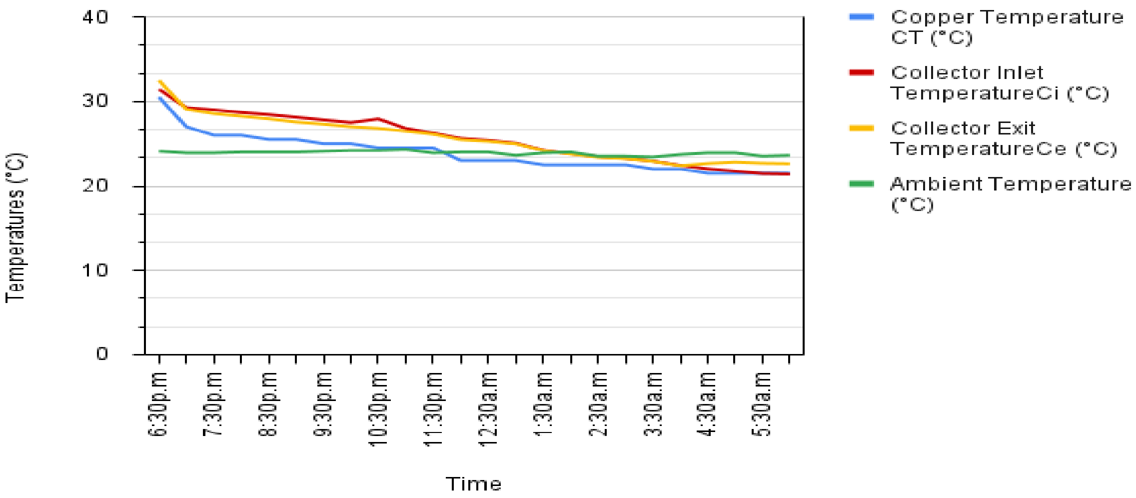

Fig. 9: Time-variant ambient, collector inlet and outlet water, and tube temperatures during nocturnal cooling

CONCLUSION

A novel hybrid solar collector comprising two 0.785m² hybrid solar thermal collectors connected in series for effective utilization of photo-thermic conversion as well as nocturnal radiative cooling was developed and experimentally investigated. The system efficiently generated heat during the day and produced cooling in the night. In the diurnal heating mode, the hybrid plate attained a maximum temperature of 68.8°C while the ambient temperature ranged from 25.3°C-30.4°C. In the nocturnal cooling mode, the hybrid plate attained a minimum temperature of 21.36°C while the ambient temperature ranged from 24.3°C-23.6°C.The results obtained during the nocturnal cooling mode show a clear night maximum water temperature drop of 10.27°C.A reasonable thermal stratification effect was observed in the storage tank throughout the 24-hours test cycle since a maximum of about 8°C difference in temperature occurred between the top water zone and the bottom zone in the tank. The overall performance of the hybrid solar thermal collector for combined heating and cooling applications compares well with data from other similar studies and shows that the system is an efficient device for producing heating and cooling effects simultaneously; thus, showing a dual-purpose seasonal adaptability and energy saving capabilities. Therefore, an incorporation of the device into a building can ensure a supply of domestic hot water for cooking, bathing and washing all year round. It can also deliver heat

for space heating during cold seasons and space cooling in hot seasons, hence offsetting the seasonal energy bills in a building.

REFERENCES

[1] Petinrinn, J.O. 2015. Renewable energy for continuous energy sustainability in Malaysia. Renewable and Sustainable Energy Reviews, 50,967-981.

[2] Gambo,B.A., Gerry,. E. 2014. Performance Evaluation of Flat Plate Solar Collector (ModelTe39) In Bauchi. American Journal of Engineering Research, 3(10) 34-40.

[3] ShahrouzAbolhosseini. 2014. A Review of Renewable Energy Supply and Energy Efficiency Technologies. IZA, Issue 8145.

[4] Shafieian,A.Khiadani,M., Nosrati,A.2019. Thermal performance of an evacuated tubeheat pipe solar water heating system in cold season, Appl. Therm. Eng. 149:644–657.

[5] Mehmood,A., Waqas, A.,Said,Z., Rahman,S.M.A., Akram, M. 2019. Performance evaluation of solar water heating system with heat pipe evacuated tubes provided with natural gas backup, Energy Rep. 5: 1432–1444.

[6] Abdullahi,D. Suresh, S., Renukappa,S., Oloke,D. 2017. Key barriers to the implementation of solar energy in Nigeria: a critical analysis. IOP Conf. Ser. Earth Environ. Sci. 83, 012015.

[7] Kalogirou, S.A. 2004. Solar thermal collectors and applications. Progress in Energy and Combustion Science, 30(3) 231-295.

[8] Iea-etsap., Irena.2015. Solar Heating and Cooling for Residential Applications. pp. 1-44.

[9] Arora, S., Chitkara, S., Udayakumar, R., Ali, M. 2011. Thermal Analysis of Evacuated Solar Tube Collectors. Journal of Petroleum and Gas Engineering, 4, 74-82.

[10] Saraf,G.R., Hamad,F.A.W.1988. Optimum tilt angle for a flat plate solar collector, Energy Convers. Manag. 28: 185–191.

[11] Kalogirou,S. 2009. Solar Energy Engineering: Processes and Systems, first ed. ed., Academic Press Publications, USA.

[12] Nwaji,G.N., Okoronkwo,C.A. Ogueke,N.V., Anyanwu,E.E. 2020. Investigation of a hybrid solar collector/nocturnal radiator for water heating/cooling in selected Nigerian cities, Renew. Energy, 145: 2561–2574.

[13] NASA.2021. NASA Prediction Of Worldwide Energy Resources. https://data.nasa.gov/Earth-Science / Prediction-Of-Worldwide-Energy-Resources-POWER-/wn3p-qsan/data?pane=manage

[14] Man, H.Y., Yang, Y. Qu, Z., Fang, A. 2015. Novel nocturnal cooling radiator used for supplemental heat sink of active cooling system, *Procedia Eng*, 121: 300–308.

[15] Imran,A.A., Jalil,J.M.,Ahmed,S.T. 2015. Induced flow for ventilation and cooling by a solar chimney, Renew. Energy 78: 236–244.

[16] Konarska, J.,Holmer,B., Lindberg,F., Thorsson,S.2016. Influence of vegetation and building geometry on the spatial variations of air temperature and cooling rates in a high-latitude city, Int. J. Climatol, 36: 2379–2395.

[17] Rabasoma, K. R. and Nwaigwe, K. N. 2020. Investigation of the thermal performance of a solar absorber and nocturnal radiator (SAANR) hybrid panel for summer and winter seasons. Heliyon. 6(12):1 – 7

[18] Yoshihiro,I., Masato,L. 2020. The influence of seasonally varying atmospheric characteristics on the intensity of nocturnal cooling in a high mountain hollow.J. Appl. Meteorol. 41: 734–743.

[19] Bokor,B.,Kajtar, L., Eryener,D.2017. Nocturnal radiation: new opportunity in building cooling, Energy Procedia 112: 118–125.

[20] Nwaji,G.N., Okoronkwo,C.A. Ogueke,N.V., Anyanwu,E.E. 2019. Hybrid solar water heating/nocturnal radiation cooling system I: a review of the progress, prospects and challenges. Energy Build, 198: 412–430.

[21] Shaaban, M., Petinrin,J.O.2014. Renewable energy potentials in Nigeria: meeting rural energy needs, Renew. Sustain. Energy Rev. 29: 72–84.

[22] Emodi,N.V. and Boo, K.J. 2015. Sustainable energy development in Nigeria: current status and policy options, Renew. Sustain. Energy Rev., 51: 356–381.

[23] Duffie, J. A. and Beckman W.A 2013, “Solar Engineering of Thermal Processes” New York, 4th edition.

[24] Kalogirou, S. A.2014. Solar Energy Engineering. 2nd ed. s.l.: Academic Press.

[25] Raman, A. P., Anoma, A. M., Zhu, L., Rephaeli, E., Fan, S. 2014. Passive radiative cooling below ambient air

temperature under direct sunlight. Nature, 515, 542.

[26] Taherian, H. 2011. Experimental validation of dynamic simulation of the flat plate collector in a closed thermosyphon solar water heater. Energy Conversion and Management, 52(1) 301-307.

[27] Okoronkwo, C.A. Nwigwe, K.N., Ogueke, N.V., Anyanwu, E.E., Onyejekwe, D.C., Ugwuoke, P.E. 2014. An experimental investigation of the passive cooling of a building using night-time radiant cooling, Int. J. Green Energy, 11, 1072–1083.

[28] Nwaigwe K.N., Okoronkwo C.A., Ogueke N.V., Ugwuoke, P.E and Anyanwu E.E. 2012 Transient Analysis of a Nocturnal Radiative Cooling of a Building in Owerri, Nigeria, Research Journal of Applied Sciences, Engineering and Technology 4(15), 2496-2506.

[29] Hosseinzadeh,E., Taherian,H. 2012. An experimental and analytical study of a radiative cooling system with unglazed flat plate collectors. Int. J. Green Energy, 9, 766–779.